Orthogonal Design and Consulting

Materials Testing Report

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Impact Gel Canada

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Date: 22 January 2015

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Summary

This report was conducted for Impact Gel Canada at the request of Dale Butterwick (University of Calgary) by Orthogonal Design and Consulting. Two different formulations of Impact Gel were tested: a soft green formulation 5.7 mm thick and a stiffer black formulation 2.1 mm thick. The materials were tested on a Bose Electroforce 3200 located at the University of Calgary.

Samples were cut into 6 mm diameter plugs for testing in unconfined compression using non-porous, stainless steel platens. To facilitate the cutting of the samples, the sheets of material were frozen to -80 ˚C and then punched with a 6 mm biopsy punch. The specimen details are shown below (Table 1). All specimens were allowed to thaw at room temperature and were tested at 20 ˚C. Dimensions were measured with a digital caliper and masses measured on a high precision digital scale.

Table 1. Material summary

	Green	Black
Thickness	5.7 mm	2.1 mm
Diameter	6.0 mm	6.0 mm
Density	1036 kg/m^3	960 kg/m^3
Date Tested	16/1/2015 to 20/1/2015	16/1/2015 to 20/1/2015

Dynamic Mechanical Analysis (DMA)

DMA was conducted to determine the energy dissipation properties of the material under cyclic load. A frequency sweep of 20 cycles followed by a brief dwell period was conducted at 10% strain for frequencies of 0.1, 0.32, 1, 3.2, 10 and 32 Hz. The tangent of the angle of phase shift between the force and displacement plots (tan delta) is equal to the ratio of the loss modulus to the storage modulus (E_{loss} / $E_{storage}$). Tan delta was strongly correlated to the frequency of oscillation using a power regression analysis for both materials (Figure 1-2). N = 3 samples were tested from each material and the averages are plotted below. Summary data are shown in Table 2.

Table 2. Tan delta vs frequency summary.

	Tan δ (Black)		Tan δ Green	
Frequency (Hz)	**Average**	**Std Dev**	**Average**	**Std Dev**
0.1	0.17	0.02	0.12	0.00
0.32	0.22	0.01	0.17	0.01
1	0.26	0.00	0.22	0.03
3.2	0.33	0.01	0.22	0.04
10	0.40	0.03	0.24	0.11
32	0.48	0.08	0.39	0.08

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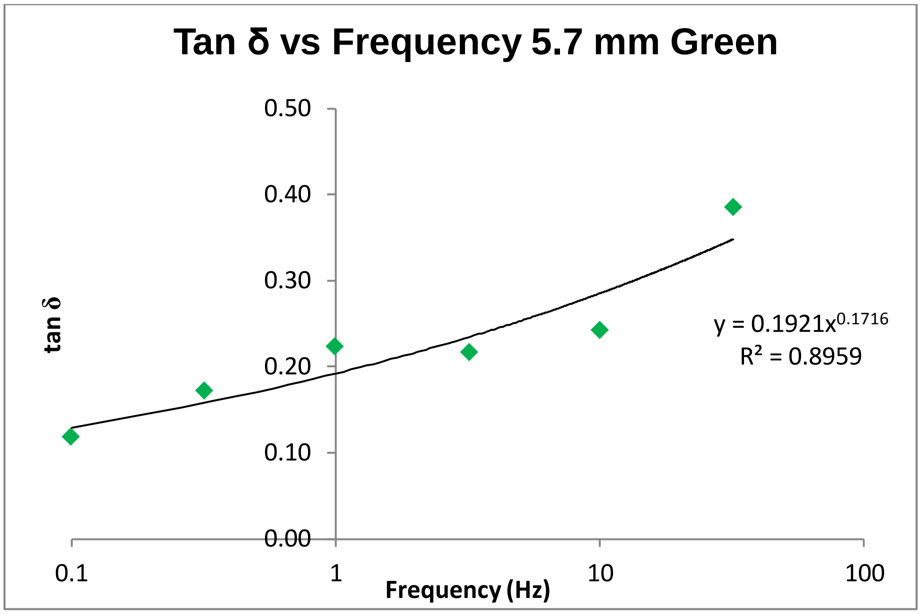

Figure 1. Tan delta vs. frequency of sinusoidal loading for the 5.7 mm green Impact Gel. Frequency is plotted on a log scale. There is increasing energy loss for increased frequency of loading.

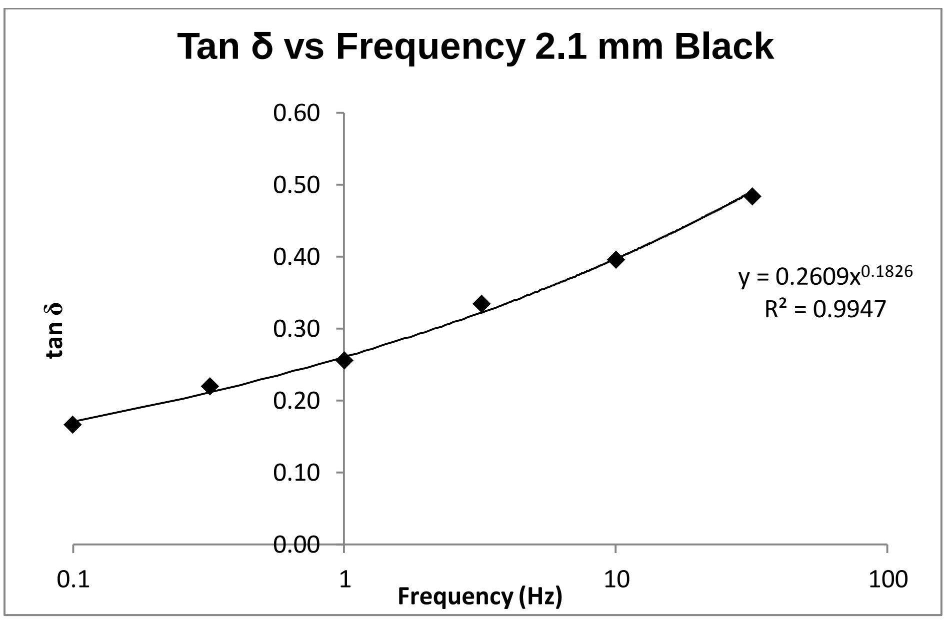

Figure 2. Tan delta vs. frequency of sinusoidal loading for the 2.1 mm black Impact Gel. Frequency is plotted on a log scale. There is increasing energy loss for increased frequency of loading.

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Stress-Relaxation Tests

To test the equilibrium modulus as a function of strain rate, a series of step displacement stress-relaxation tests were conducted. Step displacements of 3.2, 5.6, 10 and 18% strains were applied. At each strain level, the displacement was held for 150 seconds to allow stress relaxation (Figure 3). At the end of the dwell period the next displacement was applied and again allowed to stress relax. The black formulation of gel was stiffer than the green. The black material increased in stiffness for increasing strain (Figure 4a). The green material decreased in stiffness with increasing levels of strain (Figure 4b). This decrease is likely caused by the increased cross sectional area, caused by the Poisson effect of lateral expansion of the specimen. If one assumes a Poisson's ratio $\nu = 0.5$, the effect of strain dependence is negated for the green specimen (Figure 4b).

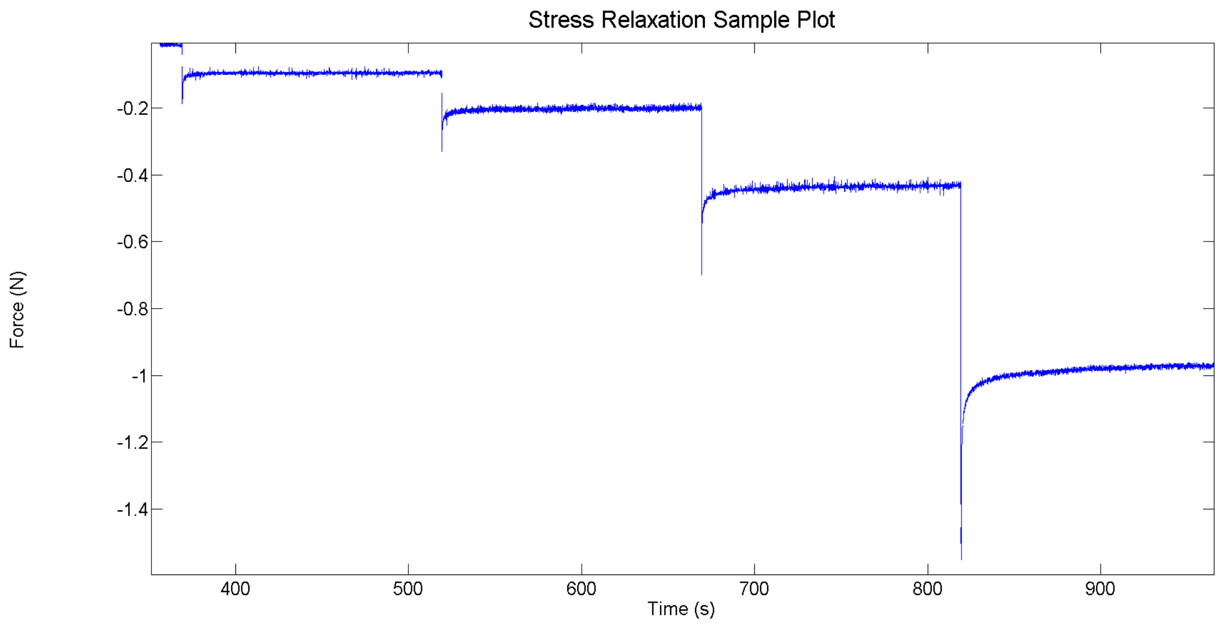

Figure 3. Representative Force vs Time plot for the stress relaxation tests conducted at 4 strain levels. Note: Negative force denotes compression.

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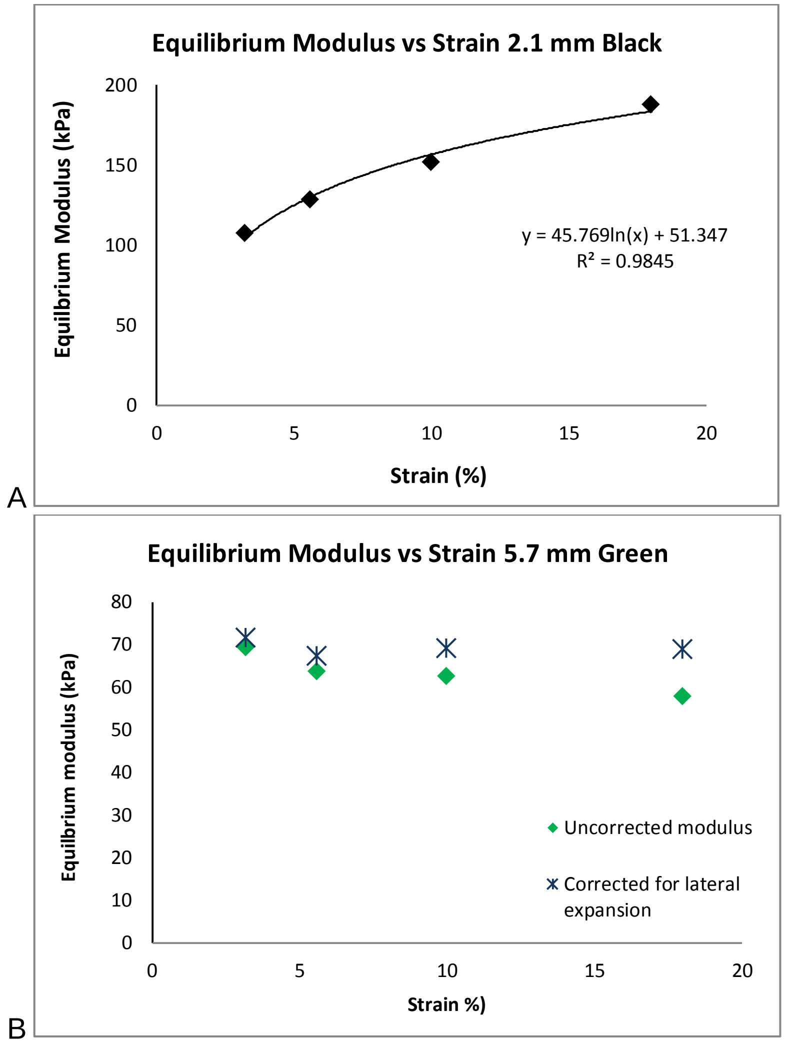

Figure 4 (A). Equilibrium modulus for black 2.1 mm gel vs strain. (B). Uncorrected and corrected modulus values for the green 5.7 mm gel vs strain.

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Strain Rate Dependence

Strain rate dependence is a property of viscoelastic materials whereby the material's stiffness is dependent on the rate of application of displacement. The gels were compressed to 10% strain at rates of 0.1%, 1%, 10% and 100%/s. Summary of the results can be found below (Table 1). Both materials exhibited strong strain rate dependence (Figure 5-6). One sample of the green material was tested 3 times to determine the within-sample repeatability of the test protocol (Figure 7). The within-sample coefficient of variation ranged from only 1.3% at 10 %/s to 5.4% at 100 %/s. Linear modulus was calculated in the linear region of the stress-strain curve. The moduli were defined as the slope of the stress/strain curve at approximately 7% strain.

Table 3. Strain-rate dependent stiffness for both green and black formulations.

	Green		Black	
Strain Rate (%/s)	Average (kPa)	Std Dev	Average (kPa)	Std Dev
0.1	68.2	2.6	204.2	2.5
1	74.8	1.7	229.4	5.1
10	84.9	1.6	278.4	18.4
100	102.5	6.5	399.7	28.8

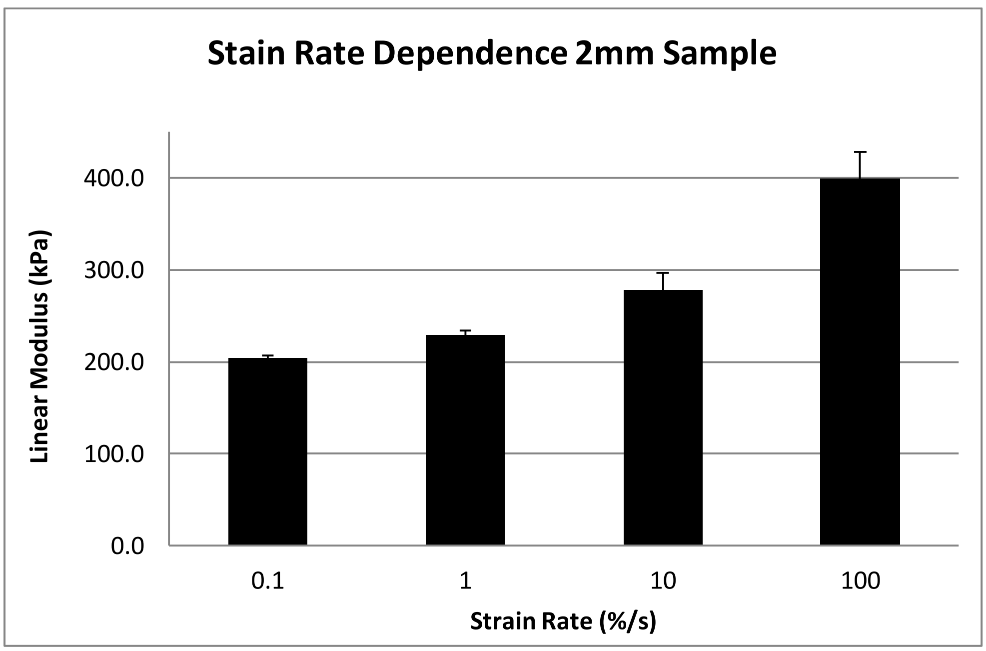

Figure 5. Linear modulus vs. strain rate for the black (2.1 mm) formulation of Impact Gel. Standard deviation of values shown atop each column.

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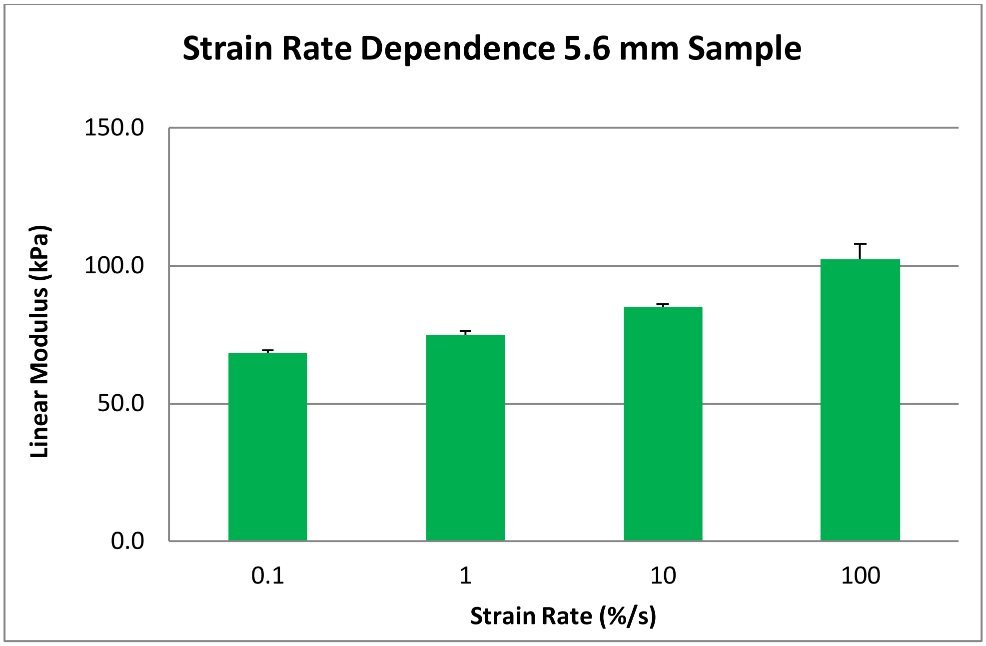

Figure 6. Linear modulus vs. strain rate for the green (5.7 mm) formulation of Impact Gel. Standard deviation of values shown atop each column.

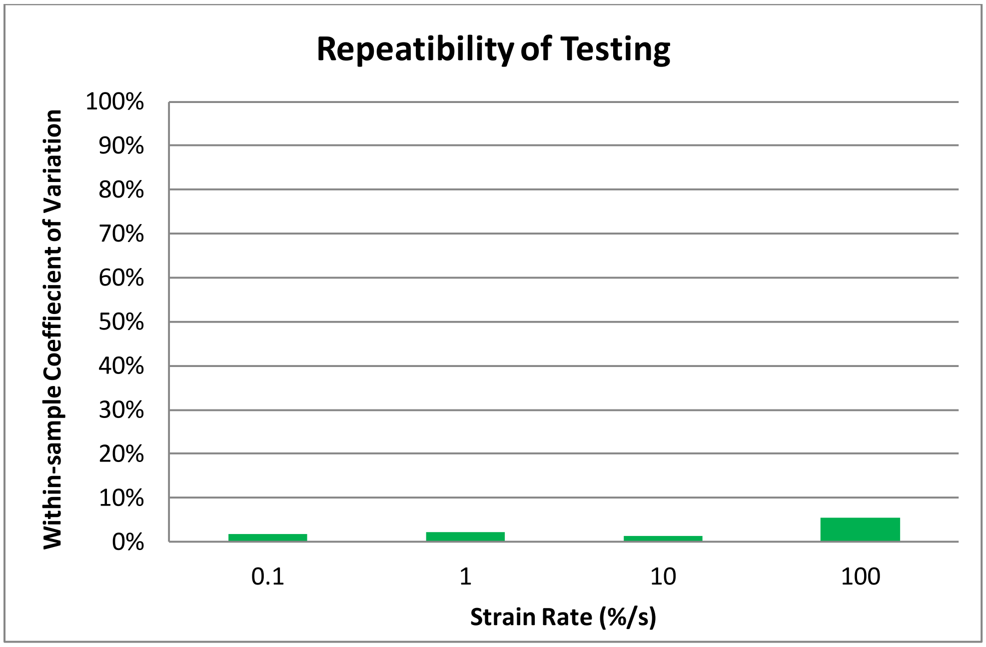

Figure 7. Within-sample variability of linear modulus vs. strain rate for green 5.7 mm formulation. Coefficient of variation (standard deviation/mean) is shown for each strain rate.

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